MULTISPECTRAL HIGH FIDELITY RADAR SCENE GENERATOR

PROGRAM PROGRESS REPORT
SBIR PHASE I; TOPIC N99-059

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This is the second monthly progress report for the Multispectral High Fidelity RADAR Scene Generator SBIR (Phase I), Contract # N68335-99-C-0126.

1.0 Work Summary

Work was done between Mar.12 and Apr.12 to define the various process blocks within the RADAR Scene Generator (RSG). The RSG overall process was separated into components and each component was broken down further into its corresponding elements until the basic physical phenomena were reached. The best description for the interconnections lends itself well to graphical representation; hence, several figures have been presented to describe how each individual contribution fits into the overall RSG.

2.0 Schedule

As anticipated in the proposal, a complete block diagram of all the processes involved in RADAR scene generation has been created. This 2nd progress report has been submitted late due to unavoidable circumstances that affected the principal investigator's schedule. Progress reporting will resume on schedule with the next progress report.

There is 1 topic (process metrics) that was expected to be addressed during this reporting period, but has been postponed due to an unexpectedly large work effort this month. The next month's work is anticipated to be light, and reporting will address leftover topics from this month's progress as well.

3.0 Studies

3.1 Input information for the Radar Scene Generator (RSG)

The first step was to consider the universe of inputs that might be expected within the RADAR scene. These inputs can be classified in various categories:

a) RADAR environment inputs:

Meteorological inputs:

Weather – Rain, snow, sleet, hail, fog
Wind -- Velocity, turbulence

Propagation Effects:

Multipath, ducting, diffraction, refraction

Earth Clutter contributors:

Land, Sea -- Distributed and discrete elements
Surface characteristics - terrain roughness, vegetation, sea state

Airborne clutter contributors:

Birds, insects, airborne dust

b) Target inputs:

Known objects:

Projectiles -- Ballistic, powered, guided
Aircraft -- fixed & rotary wing, un-powered
Surface vehicles -- land & sea based

Unknown objects:

Angels -- Any unknown object that provides discrete RADAR echoes, is visible to the main beam, but is not described above.

c) EMI:

All other signals that provide responses in the RADAR receiver. In certain RADARs, jammers can be modeled in this category. Inadvertent industrial electro-magnetic interference with the RADAR can also fall into this category once it has been characterized.

The anticipated spectral content and ERP work well as descriptions for this class of inputs.

d) Temporal Dynamics:

That describe the time vs. position behavior for all of the above. Typically, these are models that describe flight paths for the target category in the classical sense. However, bird flight paths, migration seasons and temporal insect behavior are some of the other issues that are governed by these models, as well as factory operating hours that might tell of concentrated vehicle traffic or in some cases, tell of most likely EMI sources.

e) RADAR parameters - Most modern RADARs are able to change all these parameters in real time fashion:

Antenna beam patterns (sum, delta & other auxiliary channels)
Waveform(s) – Operating frequency
Pulse Repetition Frequency
Data collection gate position
Antenna Beam position (azimuth & elevation)
Receive STC contour
Dynamic Gain Control setting (AGC, RGC etc.)

3.2 Mapping these input entities onto the RADAR grid

Now that we have defined a palette of objects that will be processed by the RADAR, we have to be able to choose and place what we need on the RADAR's measurement grid.

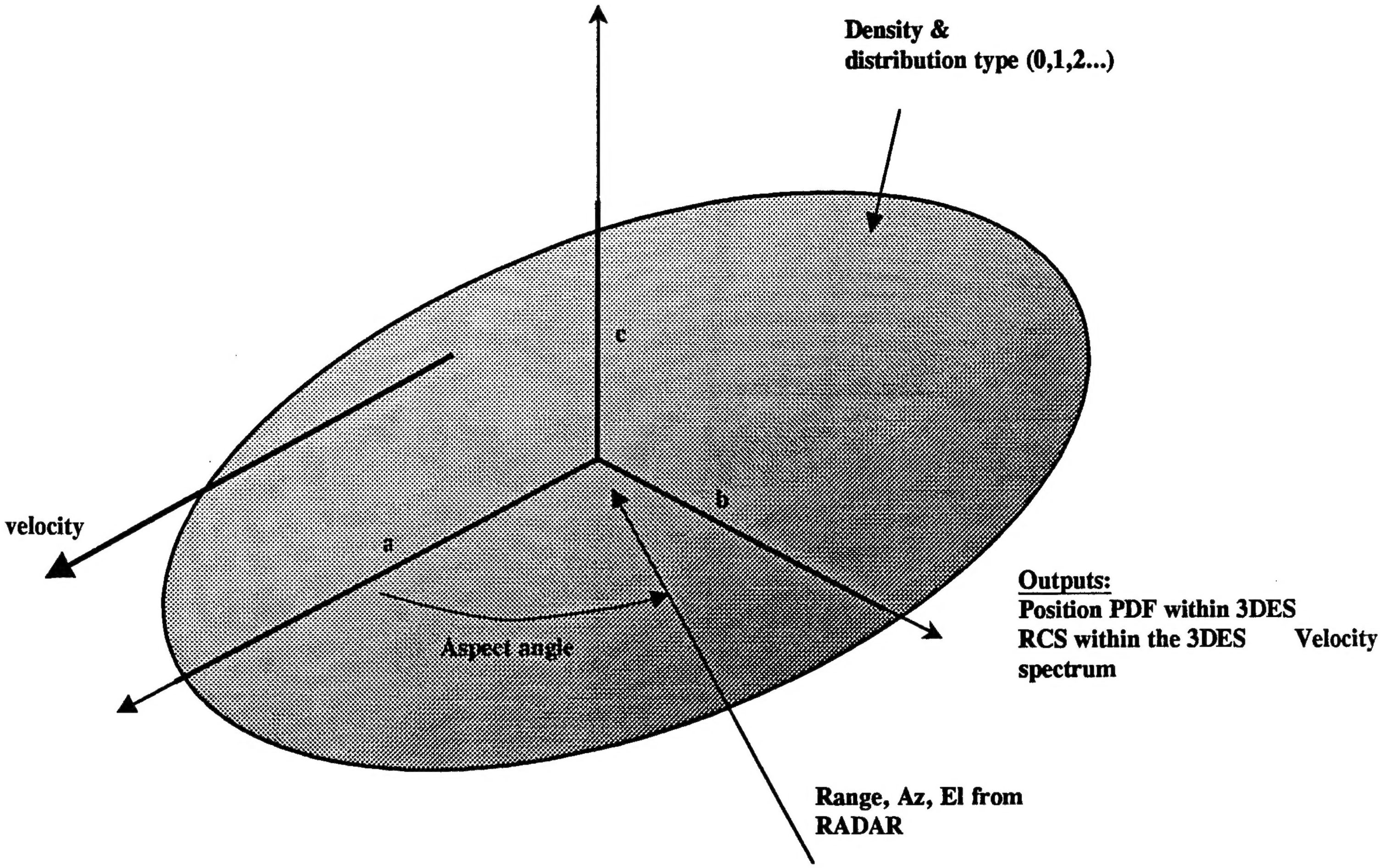
3.2.1 RADAR environment components

The RADAR environment components described in "a" will be placed in Az/El/Range space. Because of their distributed nature, these components require containment. All the components except for earth clutter are localized and therefore can be described by a boundary.

A convenient description for containment was required for the distributed clutter. An easy to describe 3 dimensional elliptical shape (3DES) was considered as the building block by which all distributed clutter could be constructed.

The RSG operator will be required to construct these 3DES entities and place them on a cartesian coordinate grid corresponding to the actual position of the phenomena. A GUI program is anticipated to be the engine for RADAR Scene definition, drawing form a DTED map for reference. Details for this interface are TBD.

Figure 1 – Pictorial Representation of 3-D Elliptical Shape (3DES)



3.2.1.1 Limiting extent of clutter components

Figure 1 pictorially describes the 3DES entity and the associated inputs and outputs. The 3DES entity is the vehicle by which distributed RADAR returns get put in the RADAR's field of view. The inputs describe the entity shape, size, distance, orientation and velocity with respect to the RADAR location, while the outputs describe the reflection amplitude and spectral characteristics of the RADAR cells within the entity.

3.2.1.1.1 Functional definition for 3DES module

The following will be the inputs to the 3DES synthesis:

a) type of entity [airborne clutter: bird, insects, dust etc, weather: rain, snow, etc]
b) position (radar relative [x/y/z])
c) size of entity along 3 axes of ellipse [m]
d) mean velocity [m/sec]
e) density [will be type dependent]
f) aspect angle [wrt Radar line of sight]
g) distribution type [probably will related to 'a'

Outputs from this module are:

a) Clutter amplitude for each of (n) Radar channels, where (n) is RADAR specific
b) Spectral table that will be used for each cell within 3DES entity

The entity description is an essential element of all RSG clutter signal synthesis.

3.2.1.2 Considering Propagation effects

This module will address the propagation effects that are visible to the RADAR. At the lower elevation angles closest to the earth, propagation is dominated by terrain features. The terrain is largely responsible for introducing multipath and diffraction into the RF signal environment. As the elevation angle increases, the propagation is increasingly influenced by meteorological phenomena such as clouds, fog, inversion layers, weather fronts etc...which in turn describe the refractive environment seen by the RF signals. This underscores the importance of correct meteorological inputs as well as accurate models of terrain reflection coefficients and accurate assessments of dielectric constant variation in air as a function of temperature, humidity and barometric pressure.

A part of the problem associated with obtaining accurate meteorological information is that the local weather conditions are often monitored by a weather RADAR. The elevation position as seen by the weather RADAR is tainted by the same propagation phenomena that the RSG is trying to characterize, hence there is some error built into the RSG output regardless of the accuracy of the propagation model.

Once the correct interfaces have been established between all the weather and earth boundaries, use of the Parabolic Wave Equation (PWE) is planned. The PWE output will be expressed in RADAR terms; namely apparent attenuation and phase shift as a function of the cartesian axes X/Y/Z. Examples of such output have been provided for low altitude ducting phenomena due to atmospheric inversion in IEEE Transactions on Antennas and Propagation Vol. 45 No. 9 pp1340 - 1347.

This information will be applied to all entities placed in a RADAR relative cartesian coordinate grid, before conversion to RADAR relative Az/El/Range coordinates and beam convolution. The PWE described effects are placed at this basic level to ensure fidelity of the anticipated effects.

One of the shortcomings of this approach is that the propagation effects in the RSG scene will be difficult to vary as a function of time. The easy way to circumvent this problem is to construct separate scenes, each with incrementally different weather conditions. This incremental technique can work well for non-real time RSG operation, but might prove cumbersome in real-time RADAR interfaces.

3.2.1.2.1 Requirements for "propagation effects" module

The GUI user interface described in 3.2.1 can be used to place the weather phenomena in the RADAR scene. For an actual RADAR site evaluation, the goal will be to receive weather information in some predetermined file format directly from the local weather station and apply the pertinent information to the RADAR scene.

As a consequence of placing weather on the scene, the RADAR relative cartesian coordinate grid will be filled with the various weather forms.

The inputs for this module will be:

a) RADAR relative X/Y/Z grid with weather phenomena (resolution TBD)
b) Various tables for reflection coefficients of land/sea. Initially, a set of default (textbook) values may be used, then updated as data becomes available.
c) Various tables with dielectric constants for air as a function of temperature humidity and barometric pressure. Once again, start with default tables, update based on data availability.
d) Access to DTED map for terrain elevation information as well as surface roughness characteristics

Outputs will be:

a) Effective attenuation and phase shift as seen from the phase center of the RADAR antenna placed on the RADAR relative cartesian coordinate grid.

Once again, recall that this information will be applied to all entities that can provide a RADAR echo.

3.2.1.3 RSG clutter generation

The business of RSG clutter signal synthesis process can be described as follows:

a) A class of clutter gets selected for consideration in the RADAR scene... This can be any sort of clutter discussed earlier. The effective RCS and spectral characteristics of the object are available through the research literature.

   For the special case of ground clutter, the grazing angle is to be computed for each "plate" defined by adjacent elevation measurements, and at the DTED map resolution. Then, the appropriate clutter backscatter coefficient is applied to each plate. This coefficient is typically dependent on the grazing angle and ground coverage (wet, dry, snow, vegetation, etc...)

b) The pertinent weather wind (or turbulence) induced modulation is computed and applied to the spectral components of the corresponding to that specific class of clutter.

c) The 3DES entity boundaries as described above limit the size of the cell(s) as they get placed by the operator on a RADAR relative cartesian coordinate grid.

d) When all the entities have been placed on the radar relative cartesian coordinate grid, the antenna beam pattern gets applied to the composite clutter at each Az/El/Range cell. This means that the antenna sidelobe contributions from other azimuth and elevation angles folded into the apparent RADAR echo put out by the RSG. This operation often referred to as "beam convolution", by necessity is performed in RADAR relative Az/El/Range space.

e) The echo amplitude is weighted as a function of range as governed by the RADAR range equation before being presented to the RADAR (model).

3.2.1.4 Functional definition for beam convolution module

The beam convolution module will accept the following inputs:

a) X/Y/Z cartesian coordinate grid at the DTED map resolution, filled with 3DES entities of the selected clutter.

b) RADAR parameters :
Azimuth beamwidth
Elevation beamwidth
Search mode range cell size(s)
Search scan sector
Antenna principal plane and off-principal plane sidelobe levels

Outputs from the Beam convolution module are:

Convolved clutter amplitude and velocity spectra at double the Az/El/Range resolution within the RADAR coverage. Recall that returns have to be computed at twice the resolution so that at "run-time" the return data can be interpolated for precision tracks that require beam positions between the quantization described by the RADAR Az/El/Range grid.

3.2.1.5 Clutter component generation

The following several figures show the path that information has to take before it finds its way to the RADAR model that the RSG is required to test:

3.2.1.5.1 Weather Clutter generation

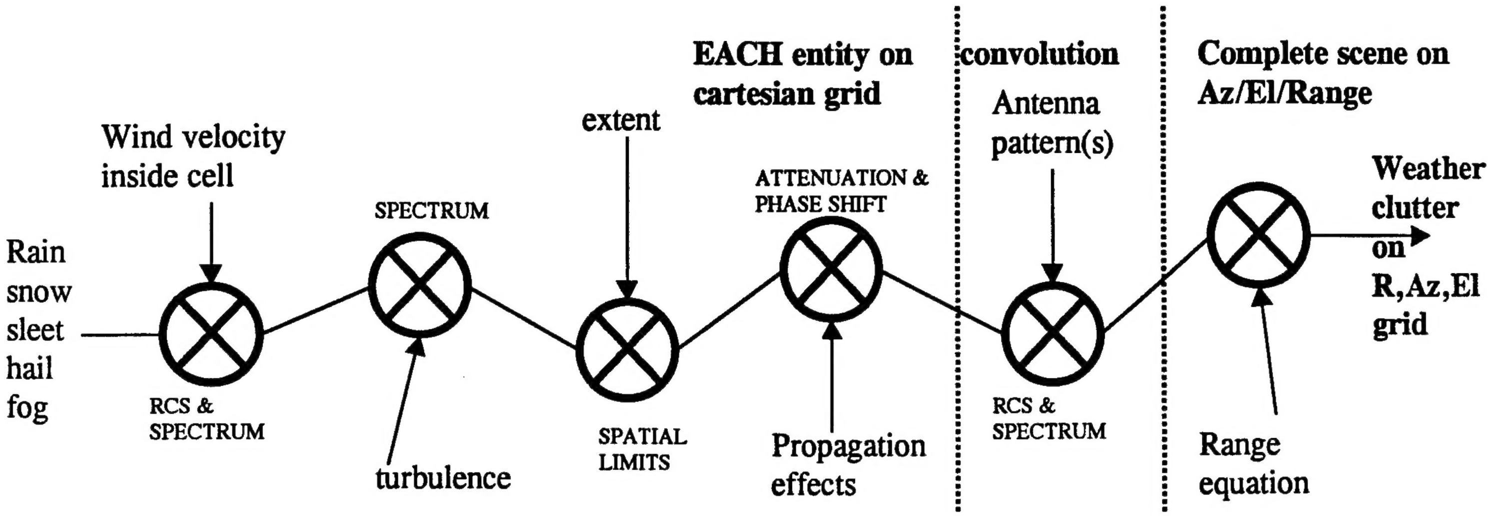


Figure 2 – Weather clutter synthesis process.

Figure 2 pictorially describes the process for synthesizing weather clutter. Each "circle X" represents a modulation process, where details have not been completely ironed out, but are different for each block. This flow graph is intended to show the process by which all the inputs discussed in para 3.1 contribute to the eventual RSG output.

The small font description in the vicinity of each "circle X" describes the attribute that the modulation will be addressing.

Weather clutter generator module

Weather Clutter - A range/Az/El grid in 75/1/1 [mtr/deg/deg] increments of clutter backscatter coefficient and velocity spectrum [m/sec]. Inputs to this module are:

a) type of weather (rain, snow, hail, sleet, fog, turbulence)
b) radar frequency
c) intensity of weather

Grid size is +45, -45 [deg] azimuth, -10, +45 [deg] elevation and 0, +300 mtr. Range.

Spectral change as a function of elevation must be considered (as the Radar beam looks up, into various precipitation).

Outputs from this module are:

c) Clutter amplitude for each of (six) Radar channels
d) Spectral table that will be used for each cell within entity

3.2.1.5.2 Earth Clutter generation

The Earth clutter generator has dual function. The first function is to provide a mask angle that the RADAR can use to place its search beam in elevation. This information has to be computed in 1 of 2 ways (operator selectable):

a) By using the DTED map information and the RADAR location to derive a line-of-sight clutter profile (called the optical mask angle). This information is used by the operator to place the elevation of the RADAR search beam.

b) By providing an elevation angle for each increment of azimuth where the earth clutter backscatter falls below an operator determined threshold. This is the radiometric mask angle. This information can be compared to the RADAR derived radiometric mask angle when this mode is available in the RADAR under test.

Figure 3 – Pictorial description of Earth clutter generation

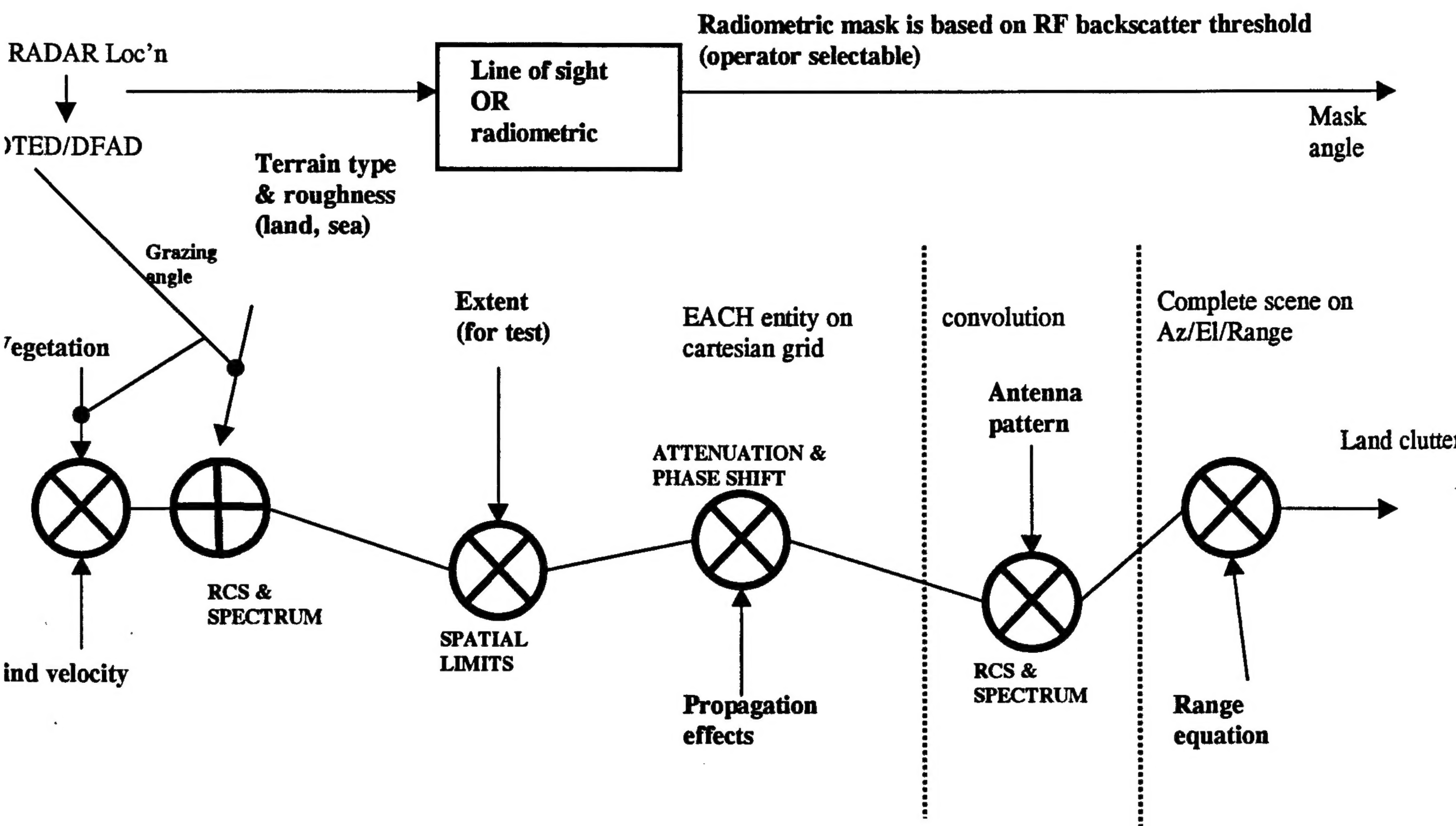


Figure 3 pictorially describes the earth clutter generation process.

There are situations where the weather clutter interacts with the earth clutter backscatter. One such example is when rain falls at sea. In this situation, the physical shape of the raindrop "bounce" on water produces extreme reflections that are frequency sensitive. This phenomenon happens not only at sea, but any time there is a body of water. There will

have to be some probabilistic assumptions made to accommodate this sort of behavior on land when puddles form.

As can be seen in figure 3, there is an opportunity to limit the clutter extent as with all the other forms of distributed clutter. This has been provided so that clutter rejection (or detection) algorithms can be developed with the aid of the RSG.

The resulting entities are placed on the RADAR relative cartesian grid, and then transformed to the RADAR Az/El/Range grid before "beam convolution". The range equation governed amplitude scaling is then applied as a matter of course.

3.2.1.5.3 Earth clutter discretes

To accommodate the situation where large stationary discrete objects exist on the surface of the earth, facility has been provided in the RSG clutter generator. Figure 4 shows the process pictorially.

The operator will be able to place discrete objects of known cross-section anywhere on the DTED map surface, or for that matter, anywhere in RADAR relative cartesian coordinate space. Typically this sort of clutter description is used to characterize urban environments where buildings might be in the RADAR's field of view, or at sea where anchored ships may be visible to the RADAR.

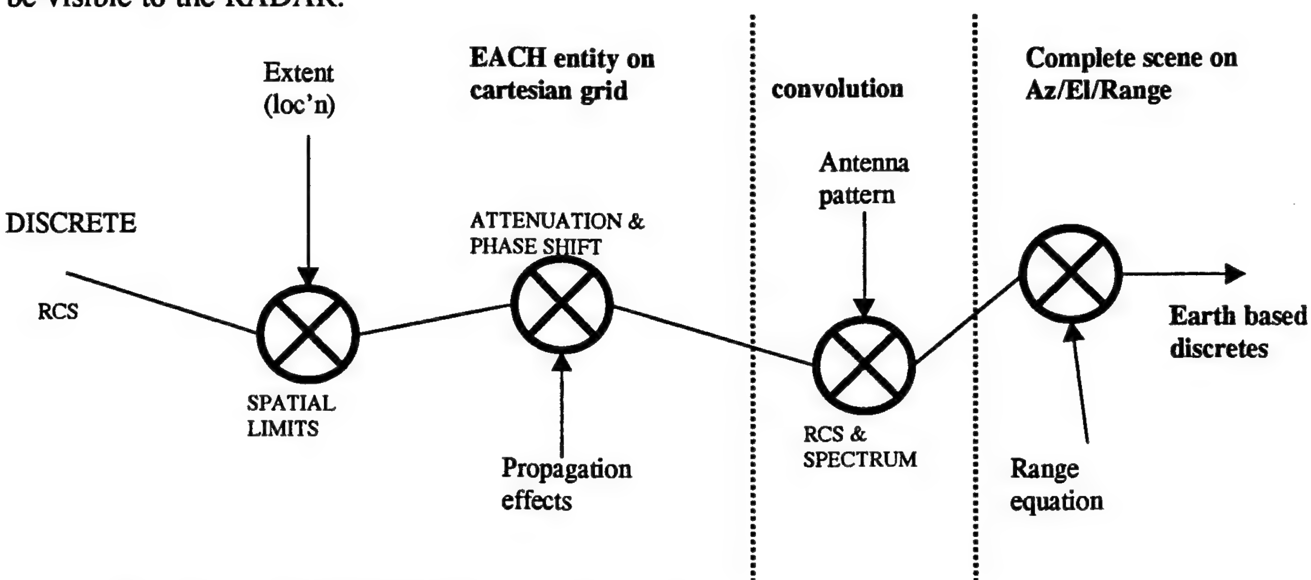


Figure 4 – Earth based clutter discretes

Once again, this process is similar to the others presented above, and is described pictorially in figure 4.

Earth Clutter generator definition

Ground clutter - A range/Az/El grid in TBD [mtr/deg/deg] increments of clutter backscatter coefficient given fixed point and direction of view on a DTED map. Other inputs to this module are:

a) Radar frequency
b) Terrain roughness
c) Sea state (if applicable)
d) Wind velocity

Discrete clutter entities will be able to be entered into the clutter map at operator chosen random points in the range/Az/El grid. Each discrete entity will have associated:

a) backscatter coefficient
b) elevation extent

Grid size Is TBD.

Outputs from this module are:

a) Range/az/el grid filled with clutter amplitudes for each of (5 ?) Radar channels
b) Spectral table that will be used for each cell

3.2.1.5.4 Airborne clutter

Distributed airborne clutter is generated through the same process as all other distributed clutter and is graphically described in figure 5.

Some of the inputs along the generation process are mutually exclusive with the class of clutter. For example, when there is significant turbulence, the likelihood of bird flocks and insect clouds is rather remote. In this situation, single bird models will have to be used, and insect clouds will have to be excluded.

A large portion of the scene validity will depend on the operator. The RSG code will have warning or advisory notices built in for unlikely combinations of clutter selection, but the operator will be given discretion to override the notices.

Airborne clutter generator definition

Sky Clutter - this form of clutter will be described by 3 dimensional elliptical entities. The operator will be able to place these entities anywhere on the range/Az/El grid. The following will be the inputs to the entity synthesis:

h) type of entity [bird, insects, dust etc]
i) position (radar relative [range/az/el] or [x/y/z])
j) size of entity along 3 axes of ellipse [m]
k) mean velocity [m/sec]
l) density [will be type dependent]
m) aspect angle [wrt Radar line of sight]
n) distribution type [probably related to 'a']

Outputs from this module are:

e) Clutter amplitude for each of (six) Radar channels
f) Spectral table that will be used for each cell within entity

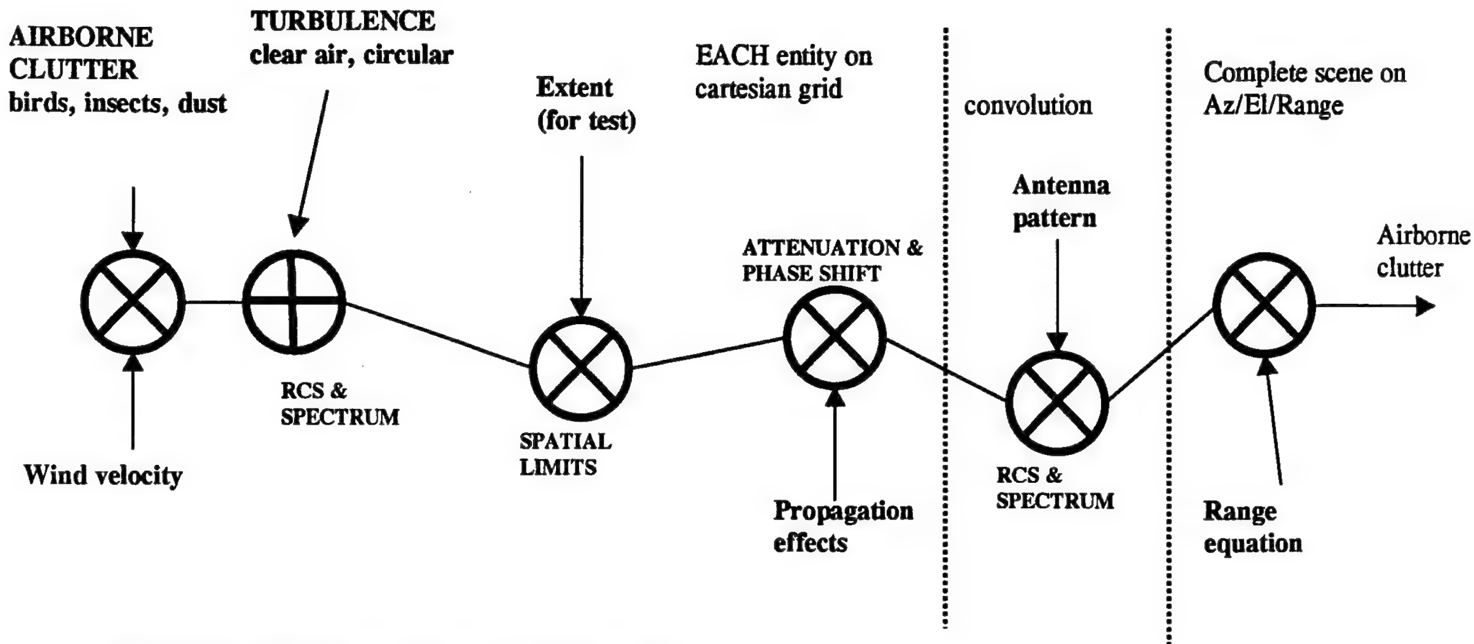


Figure 5 – Airborne clutter generation

3.2.2 Target Components

The target description covers the gamut of moving discrete objects. Because of the flexibility of the target description (described in the first progress report), this file can also include EMI, jammers and "angels" which are defined as all those objects that appear as targets on the RADAR display, but the origins of which are not understood.

Each target will require an associated behavior model. This means that a flight path will have to be generated. The flight path is fairly well determined for ballistic projectiles such as artillery and mortar shells and rockets, but airplane and helicopter flight paths will have to be generated after a dialogue with the RSG operator (for specific targets), or chosen from a default set of typical behavior for various classes of airborne targets.

For EMI and jammer behavior operator dialogue will be necessary as well. An all inclusive target generator module will be required to generate all targets.

The target generator module will have to allow the operator to generate a flight path using a set of basic lines and curves. At the ends of each segment used to construct the flight path, the velocity of the aircraft will have to be known.

For non-guided ballistic trajectories, the Modified Point Mass Model which was developed by the US Army's Ballistics Research Lab. In Aberdeen, MD is routinely used at Malibu Research and works well.

3.2.2.1Requirements for the target generator module

Delicious parameters... the following in Radar relative coordinates as a function of time in TBD1 msec increments (TBD2 msec if the rdot is > TBD3 m/sec) will be required:

a) azimuth [deg], elevation [deg], range [m]
b) rdot [m/sec],
c) elev. angle of projectile wrt local horizontal [deg]
d) aspect angle of projectile wrt line of sight to Radar [deg]

TBD1 above is related to the measurement time of the RADAR. The update rate will have to be faster than the time between 2 subsequent RADAR measurements.

TBD3 & TBD3 have to do with significant target motion within a coherent measurement interval (called a dwell). If the target moves significantly during a dwell, then the range position and Doppler frequency measurement precision of f the RADAR may be compromised depending on the sophistication of the signal processing in the RADAR. These effects have to be properly modeled by representing the target as multiple "sub-targets" in adjacent range bins and adjusting the amplitude and phase of each of the sub-target during the dwell.

Further, if the target velocity exceeds TBD4 then the time sidelobes associated with coherent detection of a phase or frequency coded pulse rise to unacceptable levels, and the range resolution of the RADAR is compromised. Once again the "sub-target" approach is used here.

Inputs to this module will be weapon type, firing geometry and pertinent meteorological information (such as wind velocity).

3.2.2.2 RCS Generation requirements

A set of RCS tables and spectral tables will be required as well to present the target in RADAR terms. RCS information consists of:

a) The projectile RCS when the transmitter and receiver have identical electrical polarization axes that are perpendicular to the radial dimension of the projectile (often called H-H response)
b) The projectile RCS when the transmitter and receiver have identical electrical polarization axes that are perpendicular to the axial dimension of the projectile (often called V-V response)
c) Relative phase angle between the H-H response and the V-V response as a function of aspect angle (often called the H-V phase).
d) A reference value [dBsm] that can be applied to the data.

This sort of RF characterization is computed using the US Army's "DICE" model or equivalently, using an Ohio State University Electroscience Laboratory software product called "Radar Cross Section - Basic Scattering Code" (RCSBSC for short). Malibu Research is in possession of RCSBSC version 2.

This RCSBSC vers.2 code is routinely used at Malibu research to estimate cross sections for various projectiles. Comparison to measured data for specific projectiles has shown remarkable agreement.

Inputs to the RCSBSC code are:

a) Definition of the shape of the object under consideration. This is done within the program using a basis set of solid geometric shapes.

b) RF frequency of operation.

Target generation is pictorially described in figure 6

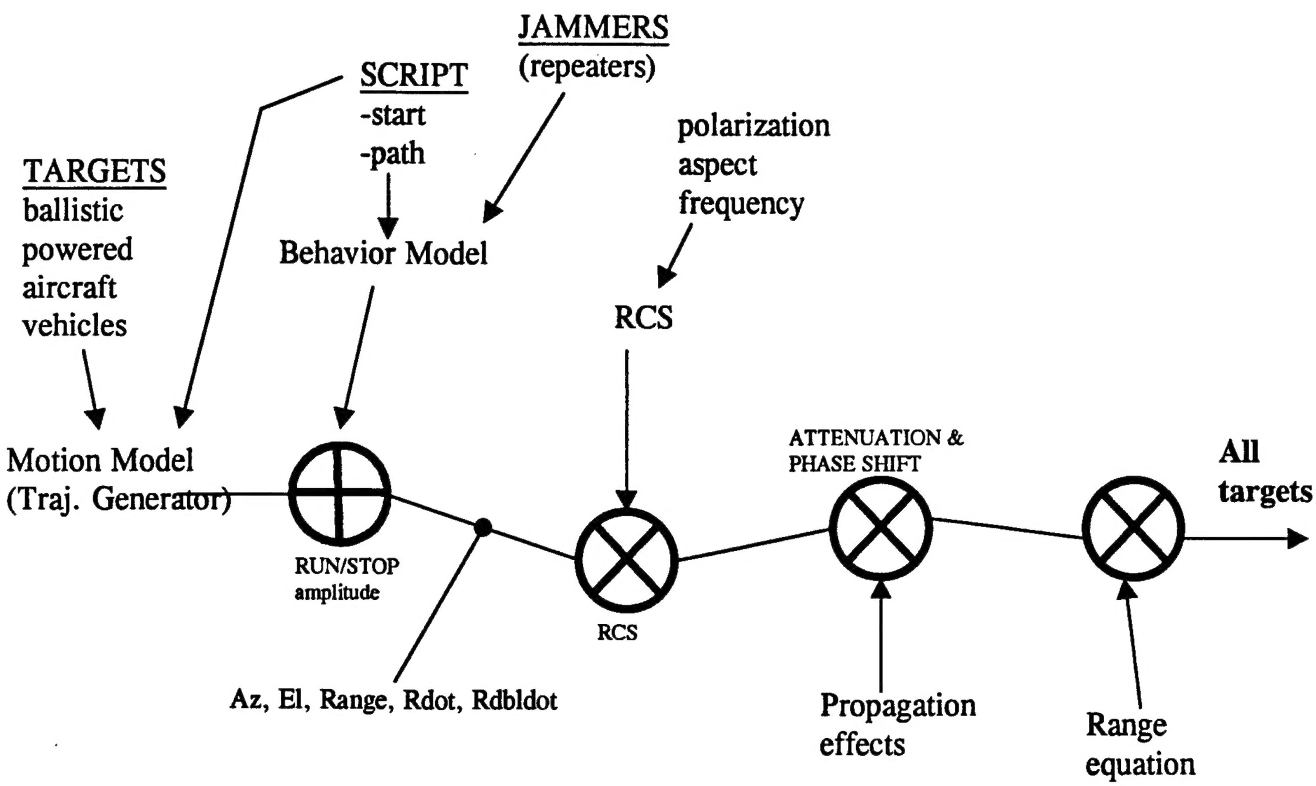


Figure 6 – Target Generator flow

3.2.3 RADAR (non-coherent) Interference module

The remaining component of the RSG is the EMI (& ECM) module. Here, the non-coherent interference will be treated as bandlimited noise sources. Once again these will be placed on the cartesian RADAR grid by the operator using the GUI program discussed in section 3.2.1.

The frequency contribution of each source will be required. For an existing RADAR in the field, the interfering noise can be measured at the site, whereas for potential RADAR designs, the spectral description of the interference can be hypothesized.

In either event, this module will pick portion of the spectrum that is consistent with the RADAR's operational frequency. Using this spectral shaping, frequency colored noise time samples will be generated for each interference source. These will be amplitude and phase adjusted based on the propagation effects discussed earlier.

Most modern RADARs use multiple receive channels for anything from angle measurement to interference rejection. Each channel has an associated phase shift relative to the main (sum beam) channel. This will be applied to the data, depending on the relative position of the interference source with respect to the antenna broadside.

The antenna weights will be applied to the output of the propagation effects (PWE) module to capture such effects as multipath before applying the range equation principles to the waveforms.

The flow for interference modeling in the RSG is presented in figure 7.

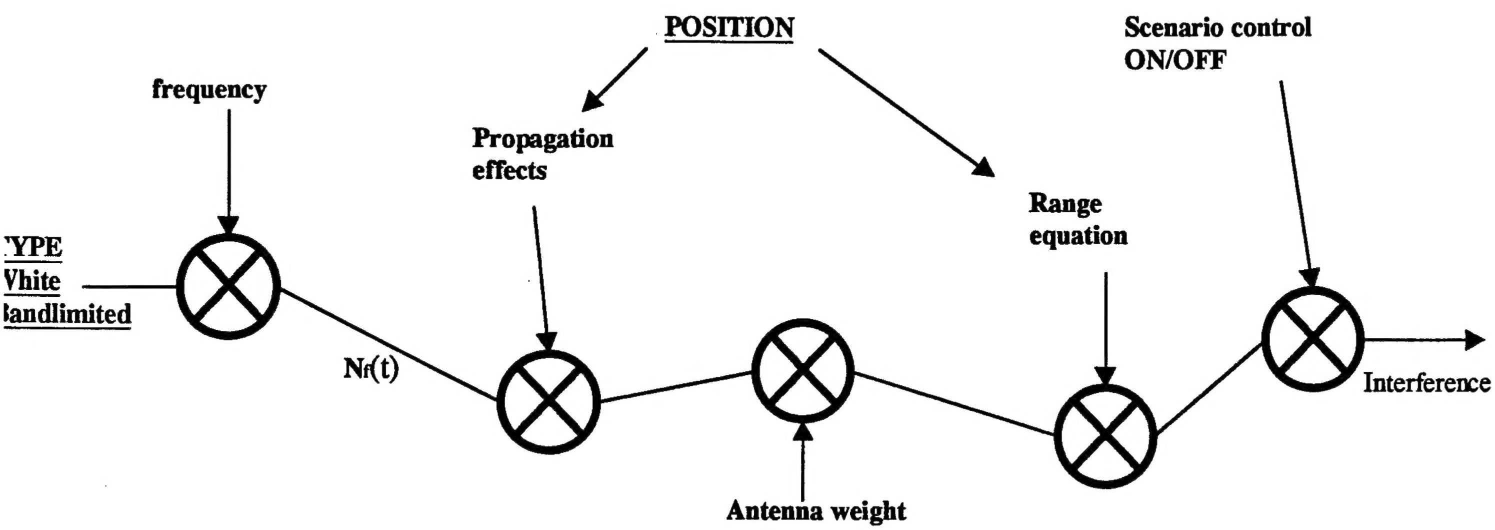


Figure 7 – Interference modeling in the RSG

3.3 The complete RADAR scene

The elements of the complete environment have been described in section 3.2 The combination of all these elements is what produces the complete RADAR scene. Figure 8 shows the simple arithmetic combination of all these components.

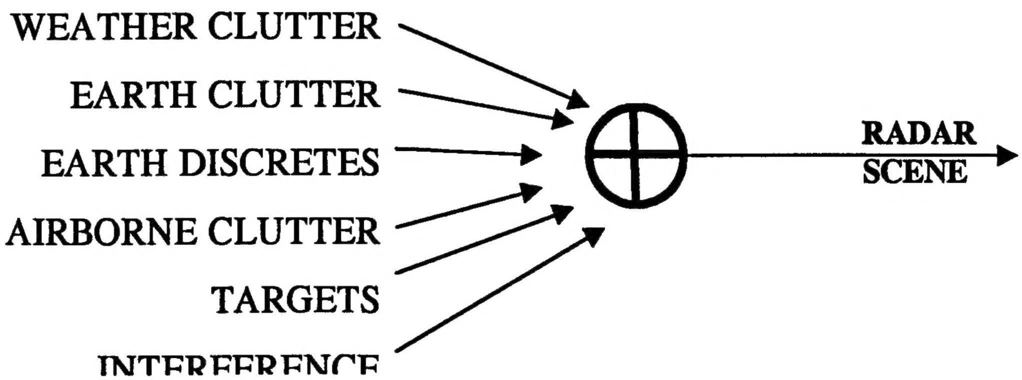


Figure 8 – Simple combination of components to create RADAR scene

There are several interactive components that allow the RSG scene to interact with the RADAR (model). These (real time) inputs have no bearing on the RADAR scene, rather, filter the portion of the scene that the RADAR beam happens to be "looking" at before application to the RADAR processor (model). The interactive components will be reported at the next progress report.

Metrics for the process blocks will consist of measuring the outputs of the blocks in some form that will validate the proper operation of the block. This will be addressed in the next report as well.

4.0 Plan for next month

1. Report on the leftover pieces identified in this report:

a) Real time inputs and their input position in the process of scene generation
b) Metrics for individual blocks to verify proper operation

2. Create schematic for a real-time RSG implementation. Describe components used in non-real time implementation

5.0 Anticipated Problems:

None